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Making Two-Channel Pricing Decisions in a Multi-Objective Closed-Loop Supply Chain Network under Uncertainty Considering Reliability (Case Study: Steel Industry)

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Abstract

Today, according to the development of the steel industry around the world, the variety of products has increased, and the products have certain complications. Due to the variety of products in this industry, the need to organize the production and manufacture of parts is felt, but the organization of the supply of raw materials, machinery, and human resources has many problems. Different supply chain networks have emerged to organize such cases, each with unique advantages and characteristics. One of the most important supply chain networks is the green supply chain network, which deals with environmental aspects in addition to economic aspects. In supply chain networks, pricing on products is very important in conditions of uncertainty, and its impact on all supply chain decisions is evident. So, by increasing or decreasing the amount of demand as well as the price of products, its effect on the amount of distribution, production, and supply is evident. Considering the importance of pricing in the closed-loop supply chain, this article discusses modeling a two-objective problem with green product strategies and pricing in the supply chain with non-deterministic maintenance costs. The goal is to maximize the profit of the entire supply chain network and maximize reliability by making the right decisions on location, routing, allocation, and inventory. The results of implementing the model in the steel industry show that the increase in reliability leads to a decrease in the profit in the supply chain network, and the increase in uncertainty in the potential demand reduces the selling price of the product. The decrease in product prices has decreased profits and reliability of the entire supply chain network. Also, by examining the model's results using the MOGWO algorithm, the effectiveness of this algorithm compared to the solution methods has been proven in terms of achieving comparison indices.

Keywords: Closed-loop supply chain, Reliability, Dual channel pricing.

1 | Introduction

The existence of competition in global markets and the desire to survive in a competitive environment has led organizations to try to improve their situation. Increasing the productivity of companies and production

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units and achieving a competitive advantage is achieved through the correct management of the supply chain network [1]. Therefore, production units are trying to reduce their costs, increase their social responsibilities, and take steps to address environmental issues by properly managing their supply chain network. The supply chain networks of production units in which the reproduction of products or the use of returned products are important in line with environmental issues are known as closed-loop supply chains [2]. In these networks, which combine forward and reverse supply chains, the goal is to manage the flow of goods from suppliers to customers and vice versa. In this type of supply chain, environmental issues are more important. The flow of goods in forward supply chains can be done through direct and indirect channels [3]. This means that products are sold to customers directly (online) without intermediaries in the direct channel. In the indirect channel, actors include distribution centers, wholesalers, and retailers. Therefore, the pricing of products in direct and indirect channels is different and is determined depending on the potential demand of each type of channel and the price of competing products. This issue strongly affects other decisions of the supply chain network, including the amount of production of new products, the amount of reproduction of products, and the amount of inventory in warehouses [4], [5]. If it is impossible to determine the potential demand accurately, this complexity is doubled. On the other hand, only the production of products in the forward supply chain is not the final goal, and meeting customers' demand in the second-hand market is also important. This amount of sales in the second-hand market depends on the amount of returned products.

The existence of uncertainty in the issue, including the demand for products in the first and second-hand market, as well as transportation costs, leads to it. This makes it difficult to make strategic and tactical decisions, such as locating centers, determining the optimal amount of production and distribution, determining the optimal amount of inventory, and routing products for transportation. This uncertainty affects the pricing of products in direct and indirect channels and overshadows the company's competitiveness. In this article, the importance of this issue has led to using the fuzzy programming method to control these parameters in the model and help managers make appropriate decisions. The closed-loop supply chain network was designed in this article to respond to important strategic and tactical decisions under the two objective functions of minimizing the costs of the entire supply chain network and maximizing reliability. The higher the reliability of the supply chain network, the higher the demand from customers. Meanwhile, the increase in reliability increases the costs of the supply chain network and reduces its profit.

The decisions that are taken to optimize the mentioned objective functions include locating production units, distribution centers, and collection centers, determining the optimal selling price of products in direct and indirect channels, determining the optimal amount of inventory and the optimal flow of products among the levels of the supply chain network. Due to two opposing objective functions, a meta-heuristic algorithm has been used. It is also a review of the results of the steel industry in Iran.

The article's structure is as follows. In the second part, the research literature review is discussed. The third part describes the mathematical model of the closed-loop supply chain network under uncertainty and using the fuzzy programming method. The results are analyzed in the fourth part, and in the fifth part, the research conclusions are stated.

2 | Literature Review

The importance of the closed-loop supply chain network has led many researchers to study and model the closed-loop supply chain network. Therefore, this section discusses the literature review of the closed loop supply chain network and identifies the research gap at the end.

Sahebjamnia et al. [6] presented a multi-objective different integer linear programming model for sustainable closed-loop supply chain network design. This model aimed to minimize the total costs and emissions of harmful gases in the tire industry. The results show that the combined algorithms are more efficient in solving the closed-loop supply chain model. Rahmani and Yavari [7] presented a two-channel product pricing model based on the Stackelberg game, where demand is assumed to be non-deterministic. They showed that increased market scale caused by disruption, lower green cost, and lower level of customer loyalty to the retail

channel are beneficial to the supply chain and lead to further improvement in the level of greenness of green products. Hasanov et al. [8] designed a four-level supply chain network in which product reproduction is also considered. The purpose of designing this model is to achieve production policies (manufacturing and reproduction) and inventory determination. The results obtained from the model show that the higher collection rate of used items reduces supply chain costs and improves environmental performance.

Govindan et al. [9] presented a mathematical model related to the inventory-location-routing problem in a multi-product closed-loop supply chain where the objective was to minimize total and shortage costs. Due to uncertainty in the designed network, a fuzzy solution approach was used to simultaneously incorporate the uncertainty and transform the multi-objective model into a single-objective model. The obtained results show the compatibility of the model with environmental conditions. Rahmani et al. [10] presented a mathematical model based on a two-channel system for green supply chain design, in which products are purchased from production units directly and indirectly. In this model, determining the optimal price of products in each channel was one of the most important decisions of the network, which had a significant impact on the objective function. Cultural and genetic algorithms were used to solve the invasive weed algorithm model. Ghahremani-Nahr et al. [11] presented a multi-level, multi-period, and multi-product model in a closed-loop supply chain network in which to minimize the costs of the entire supply chain network, genetic algorithm, colonial competition, particle swarm, colony Bees, and refrigeration simulations were used. Due to the uncertainty in the problem's parameters, the robust possibility optimization approach was used. The results showed that the genetic algorithm is highly efficient in solving the model.

Salehi-Amiri et al. [12] presented a developed model of a closed-loop supply chain network for the agricultural industry (walnut). They proposed a mixed integer linear programming mathematical model for the network that minimizes the total costs of the walnut industry. A set of meta-heuristic algorithms was used to solve the proposed model, and the results dramatically showed excellent compatibility between the proposed network and the algorithms used. Fathollahi-Fard et al. [13] modeled a two-channel, multi-product, multi-period closed-loop supply chain for the tire industry under uncertainty of price and demand parameters. They used Khomeins' fuzzy approach to control non-deterministic parameters to optimize the total network profit. Also, the objective function has been optimized through meta-heuristic algorithms such as the red deer algorithm and the whale optimization algorithm. The results show that determining the appropriate prices in different channels for different types of tires can affect supply chain management.

Khorshidvand et al. [14] introduced a model for optimizing economic and environmental aspects in a closed-loop supply chain, where pricing, greenness, and advertising decisions were made. Due to the indeterminacy of the demand parameter, the robust optimization approach has been used. The results indicate an improvement in the performance of economic and environmental goals under green decisions and advertising. Barman et al. [15] presented a two-channel model for product sales, in which sales are made directly and indirectly. The considered model consisted of a producer and a bushel. The purpose of this profit maximization model is stated under the centralized and decentralized structure, and the Skettleberg game approach is used to solve it. Nasr et al. [16] presented a new two-stage fuzzy supplier selection model and order allocation in a closed-loop supply chain network. In the first stage, they used the best-worst fuzzy method to select the most appropriate suppliers according to economic, environmental, and social criteria. Also, in the second stage, they introduced a multi-objective mixed integer linear programming model to design a multi-product, multi-period network, where inventory-location-routing decisions, vehicle scheduling, and quantitative discount considerations were considered.

Soleimani et al. [17] designed a sustainable closed-loop supply chain that includes suppliers, manufacturers, distribution centers, customer areas, and disposal centers, considering energy consumption. The presented model aimed to simultaneously optimize the profit of the entire supply chain, energy consumption, and the number of job opportunities created. They used the Lagrange release method to solve the problem and showed the efficiency of their solution. Tirkolaee et al. [18] presented a new mathematical model to design a sustainable closed-loop supply chain network for mask products under the conditions of COVID-19. In this

model, decisions related to the location of suppliers, production and distribution centers, collection, and recycling are made. Also, the goal of the sustainability of the problem was to minimize total costs, pollution, and human error simultaneously. To achieve the Pareto front, they used MOGWO and NSGA II algorithms. Musavi et al. [19] presented a pricing decision problem for organic and conventional agricultural products in a food supply chain. This study focuses on designing different distribution channel structures and highlighting their impact on optimal decisions. Direct sales channel model, centralized two-channel model, decentralized leader-follower two-channel model, and coordinated two-channel with revenue sharing contract are designed to analyze optimal pricing solutions. Das et al. [20] investigated a two-channel supply chain considering the greenness level of items.

Wang et al. [21] developed a set of game models in a two-channel closed-loop supply chain in which the retailer is considered the leader and the manufacturer is the follower. One of the most important decisions in the current network is determining the retailer's optimal price in the closed-loop supply chain network. Keshavarz-Ghorbani and Arshadi Khamseh [22] addressed the repair process to improve the virtual era of used products and integration in the forward flow as a closed-loop supply chain.

By reviewing the literature review, it can be stated that there is no comprehensive model of the closed-loop supply chain network that deals with pricing, positioning, routing, and inventory simultaneously. Therefore, this article attempts to fill the research gap by designing a dual-objective model of the closed-loop supply chain network with profit and reliability maximization objectives. Strategic decisions, such as the location of facilities, and tactical decisions, such as pricing of products in direct and indirect channels, determination of warehouse inventory, transportation routing, and the optimal amount of flow, are specified. Considering the existence of uncertainty in the network, the fuzzy programming method has been used to control the non-deterministic parameters.

3 | Definition of the Problem and Modeling

According to *Fig. 1*, in this article, a supply chain network model has been presented to meet the uncertain demand of customers and make appropriate decisions regarding the pricing of products in direct and indirect distribution channels. Different levels are considered in this network. At first, production units produce new products in the market. The products produced are sent to customers directly or through an indirect channel consisting of levels (warehouses and distributors) to customers. In this network, the pricing in two channels, direct and indirect, depends on the price elasticity according to the demand in the two markets, and according to the type of demand, the price of the products in these two markets is determined. In the reverse supply chain, the collection center collects a percentage of the customers' products. After inspection, a percentage of the products that can be sold in the second-hand market are sent to the production units. After receiving the products, the production units send them to the second-hand market for sale at a known price.

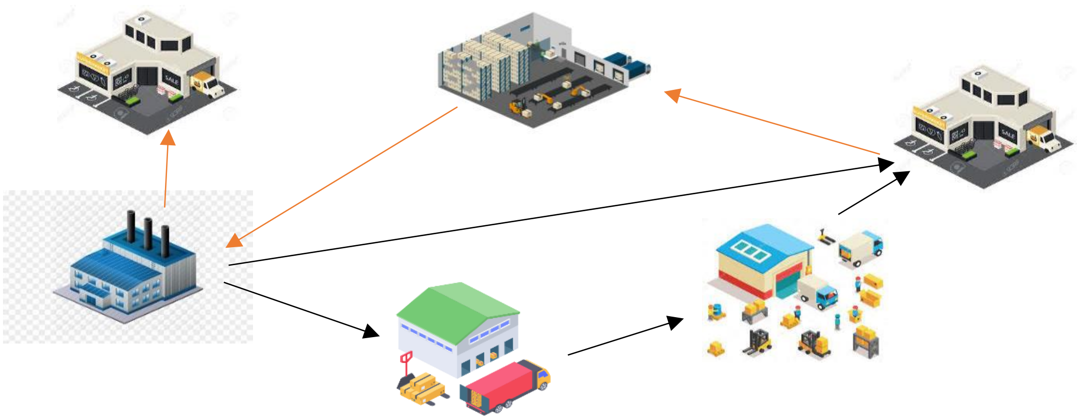

Fig. 1. Closed-loop supply chain network.

In this paper, the main goal is to maximize the profit from the sale of products in direct and indirect channels as well as the second-hand market. Also, the second objective function is considered reliability maximization. The developed model can be modeled according to the following assumptions:

I. It is a multi-period and single-product model.

II. Customer demand exists in the first-hand market from two direct and indirect channels.

III. The product's price depends on the substitute product's potential demand and price elasticity.

IV. Demand, transportation, and storage costs are assumed to be uncertain.

V. The emission of greenhouse gases in the network should not exceed the permissible limit.

VI. The capacity of all facilities is known in advance.

VII. Production centers have different technologies for product production.

VIII. There is a shortage in the first-hand and second-hand markets.

Sets

I	The set of potential production units $i \in \{1,2,\ldots,I\}$.
D	The set of warehouses $d \in \{1,2,\ldots,D\}$.
J	The set of distribution centers $j \in \{1,2,\ldots,J\}$.
C	Collection of collection centers $c \in \{1,2,\ldots,C\}$.
K	The total set of customers $k \in \{K' \cup K''\}$.
K'	The set of first-hand market customers $k' \in \{1,2,\ldots,K'\}$.
K''	The set of customers of the second-hand market $k^{\wedge''} \in \{1,2,\ldots,K^{\wedge''}\}$.
V	The set of transportation options $v \in \{1,2,\ldots,V\}$.
T	The set of time periods $t \in \{1,2,\ldots,T\}$.
N	Production technology set $n \in \{1,2,\ldots,N\}$.

Parameters

$\widetilde{de}_{k',t}$	The amount of uncertain customer demand $k' \in K'$ of the new product in the time period $t \in T$.
$\widetilde{de}_{k'',t}$	The amount of non-deterministic customer demand $k'' \in K''$ of the second-hand product in the time period $t \in T$.
$\lambda_{k'}$	Price elasticity and product substitution in the direct channel for customer $k' \in K'$.
$\lambda'_{k'}$	Price elasticity and product substitution in the indirect channel for customer $k' \in K'$.
γ_1	Price elasticity based on customer demand $k' \in K'$ in the direct channel.
γ_2	Price elasticity based on customer demand $k' \in K'$ in the indirect channel.
ρ	The average rate of return products in all periods.
σ	The percentage of products that can be recycled and sold in the second-hand market.
CI_i	The maximum capacity of production unit $i \in I$ of new products.
CI'_i	The maximum capacity of production unit $i \in I$ of second-hand products.
CD_d	The maximum storage capacity of new products in the warehouse $d \in D$.

CJ_j	Maximum distribution capacity of new products in distribution center $j \in J$.
CC_c	Maximum capacity of collection and inspection of returned products in the collection center $c \in C$.
φ_i	The maximum amount allowed for greenhouse gas emission in production unit $i \in I$.
ζ_n	The amount of greenhouse gas emissions in the production of a new product due to the use of technology level $n \in N$.
u_v	The amount of greenhouse gas emissions due to the transportation of the product with the transportation option $v \in V$.
$\aleph$	The total amount allowed for the emission of greenhouse gases due to the transfer of the product between the levels of the supply chain network.
Fv_i	Fixed cost of construction of production unit $i \in I$.
Fw_j	The cost of building a distribution center $j \in J$.
Ft_c	The cost of building a collection center $c \in C$.
PR_t	The price of the product in the second-hand market in the time period $t \in T$.
$\widetilde{H}_t$	The maintenance cost of the new product in the time period $t \in T$.
$\pi_{k',t}$	Penalty cost of not estimating customer demand $k' \in K'$ of the new product in the time period $t \in T$.
$\pi'_{k'',t}$	Penalty cost of not estimating customer demand $k'' \in K''$ of second-hand product in time period $t \in T$.
$\widetilde{Tr}_v$	Transportation cost per kilometer by transportation option $v \in V$.
λv_i	Failure rate of production unit $i \in I$.
λw_j	Failure rate of distribution center $j \in J$.
λt_c	Collection center failure rate $c \in C$.
α	Uncertainty rate.

Decision variables

$d_{k',t}$	Customer demand $k' \in K'$ of new product in the direct channel in time period $t \in T$.
$d'_{k',t}$	Customer demand $k' \in K'$ of new product in indirect channel in time period $t \in T$.
PD_t	The price of the product in the direct channel in the time period $t \in T$.
PI_t	The price of the product in the indirect channel in the time period $t \in T$.
$\delta_{k',t}$	The amount of unfulfillment of customer demand $k' \in K'$ of the new product in the direct channel in the time period $t \in T$.
$\delta'_{k',t}$	The amount of unfulfillment of customer demand $k' \in K'$ of the new product in the indirect channel in the time period $t \in T$.
$\delta''_{k'',t}$	The amount of unfulfillment of customer demand $k'' \in K''$ of the second-hand product in the time period $t \in T$.
$Y_{i,k',v,t}$	The amount of new product transferred between production unit $i \in I$ and customer $k' \in K'$ through transport option $v \in V$ in time period $t \in T$.

$Z_{j,k',v,t}$	The quantity of the new product transferred between the distribution center $j \in J$ and the customer $k' \in K'$ through the transport option $v \in V$ in the time period $t \in T$.
$N_{i,k'',v,t}$	Amount of second-hand product transferred between production unit $i \in I$ and customer $k'' \in K''$ through transport option $v \in V$ in time period $t \in T$.
$X_{d,j,v,t}$	The amount of new product transferred between warehouse $d \in D$ and distribution center $j \in J$ through transport option $v \in V$ in time period $t \in T$.
$Q_{d,t}$	The amount of new product stored in warehouse $d \in D$ at the end of time period $t \in T$.
$S_{i,d,v,t}$	Amount of new product transferred between production unit $i \in I$ and warehouse $d \in D$ through transportation option $v \in V$ in time period $t \in T$.
$O_{k',c,v,t}$	Returned product value between customer $k' \in K'$ and collection center $c \in C$ through transport option $v \in V$ in time period $t \in T$.
$P_{c,i,v,t}$	Returned product amount between collection center $c \in C$ and production unit $i \in I$ through transportation option $v \in V$ in time period $t \in T$.
V_i	If the production unit $i \in I$ is built, it takes the value of 1, and otherwise, it takes the value of 0.
W_j	If the distribution center $j \in J$ is established, it takes the value of 1, and otherwise, it takes the value of 0.
T_c	If the collection center $c \in C$ is built, it takes the value of 1, and otherwise, it takes the value of 0.
$\vartheta_{i,n}$	If the production unit $i \in I$ uses the technology level $n \in N$, it takes the value of 1, and otherwise, it takes the value of 0.

$$\max Z_1 = \sum_{i\in I}\sum_{k'\in K'}\sum_{v\in V}\sum_{t\in T} PD_t.Y_{i,k',v,t} + \sum_{j\in J}\sum_{k'\in K'}\sum_{v\in V}\sum_{t\in T} PI_t.Z_{j,k',v,t} + \sum_{i\in I}\sum_{k''\in K''}\sum_{v\in V}\sum_{t\in T} PR_t.N_{i,k'',v,t} - \left(\sum_{i\in I} Fv_i.V_i + \sum_{j\in J} Fw_j.W_j + \sum_{c\in C} Ft_c.T_c\right) - \left(\sum_{d\in D}\sum_{t\in T}\left[\frac{H_t^1+H_t^2+H_t^3}{4}\right].Q_{d,t} + \sum_{k'\in K'}\sum_{t\in T}\pi_{k',t}\left(\delta_{k',t}+\delta'_{k',t}\right) + \sum_{k''\in K''}\sum_{t\in T}\pi'_{k'',t}.\delta''_{k'',t}\right) - \sum_{v\in V}\sum_{t\in T}\left[\frac{Tr_v^1+Tr_v^2+Tr_v^3}{4}\right]\left(\sum_{i\in I}\sum_{d\in D}S_{i,d,v,t} + \sum_{k'\in K'}\sum_{i\in I}Y_{i,k',v,t} + \sum_{d\in D}\sum_{j\in J}X_{d,j,v,t} + \sum_{k'\in K'}\sum_{j\in J}Z_{j,k',v,t} + \sum_{k'\in K'}\sum_{c\in C}O_{k',c,v,t} + \sum_{c\in C}\sum_{i\in I}P_{c,i,v,t} + \sum_{k''\in K''}\sum_{i\in I}N_{i,k'',v,t}\right), \tag{1}$$

$$\max Z_2 = \sum_{v\in V}\sum_{t\in T}\left(\sum_{i\in I}\sum_{d\in D}e^{-\lambda v_i}S_{i,d,v,t} + \sum_{k'\in K'}\sum_{i\in I}e^{-\lambda v_i}Y_{i,k',v,t} + \sum_{k'\in K'}\sum_{j\in J}e^{-\lambda w_j}Z_{j,k',v,t} + \sum_{c\in C}\sum_{i\in I}e^{-\lambda t_c}P_{c,i,v,t} + \sum_{k''\in K''}\sum_{i\in I}e^{-\lambda v_i}N_{i,k'',v,t}\right), \tag{2}$$

$$\text{s.t.:}$$

$$d_{k',t} = \left[\alpha.\left(\frac{de^2_{k',t}+de^3_{k',t}}{2}\right) + (1-\alpha).\left(\frac{de^1_{k',t}+de^2_{k',t}}{2}\right)\right] - \lambda_{k'}.PD_t + \gamma_1.PI_t, \text{ for all } k' \in K', t \in T, \tag{3}$$

$$d'_{k',t} = \left[\alpha.\left(\frac{de^2_{k',t}+de^3_{k',t}}{2}\right) + (1-\alpha).\left(\frac{de^1_{k',t}+de^2_{k',t}}{2}\right)\right] - \lambda'_{k'}.PI_t + \gamma_2.PD_t, \text{ for all } k' \in K', t \in T, \tag{4}$$

$$\sum_{i\in I}\sum_{v\in V} Y_{i,k',v,t} + \delta_{k',t} = d_{k',t}, \quad \text{for all } k' \in K', t \in T, \tag{5}$$

$$\sum_{j\in J}\sum_{v\in V} Z_{j,k',v,t} + \delta'_{k',t} = d'_{k',t}, \quad \text{for all } k' \in K', t \in T, \tag{6}$$

$$\sum_{i\in I}\sum_{v\in V} N_{i,k'',v,t} + \delta''_{k'',t} = \left[\alpha.\left(\frac{de^2_{k'',t}+de^3_{k'',t}}{2}\right) + (1-\alpha).\left(\frac{de^1_{k'',t}+de^2_{k'',t}}{2}\right)\right], \text{ for all } k'' \in K'', t \in T, \tag{7}$$

$$\sum_{k'\in K'}\sum_{v\in V} Z_{j,k',v,t} = \sum_{d\in D}\sum_{v\in V} X_{d,j,v,t}, \quad \text{for all } j \in J, t \in T, \tag{8}$$

$$Q_{d,t} = \sum_{i\in I}\sum_{v\in V} S_{i,d,v,t} + Q_{d,t-1} - \sum_{j\in J}\sum_{v\in V} X_{d,j,v,t}, \quad \text{for all } d \in D, t \in T, \tag{9}$$

$$\sum_{c\in C}\sum_{v\in V} O_{k',c,v,t} = \rho\left(\sum_{i\in I}\sum_{v\in V} Y_{i,k',v,t} + \sum_{j\in J}\sum_{v\in V} Z_{j,k',v,t}\right), \quad \text{for all } k' \in K', t \in T, \tag{10}$$

$$\sigma \sum_{k'\in K'}\sum_{v\in V} O_{k',c,v,t} = \sum_{i\in I}\sum_{v\in V} P_{c,i,v,t}, \quad \text{for all } c \in C, t \in T, \tag{11}$$

$$\sum_{c\in C}\sum_{v\in V} P_{c,i,v,t} = \sum_{k''\in K''}\sum_{v\in V} N_{i,k'',v,t}, \quad \text{for all } i \in I, t \in T, \tag{12}$$

$$\sum_{d\in D}\sum_{v\in V} S_{i,d,v,t} + \sum_{k'\in K'}\sum_{v\in V} Y_{i,k',v,t} \le CI_i.V_i, \quad \text{for all } i \in I, t \in T, \tag{13}$$

$$\sum_{k'\in K'}\sum_{v\in V} Z_{j,k',v,t} \le CJ_j.W_j, \quad \text{for all } j \in J, t \in T, \tag{14}$$

$$\sum_{k'\in K'}\sum_{v\in V} O_{k',c,v,t} \le CC_c.T_c, \quad \text{for all } c \in C, t \in T, \tag{15}$$

$$Q_{d,t} \le CD_d, \text{ for all } d \in D, t \in T, \tag{16}$$

$$\sum_{c\in C}\sum_{v\in V} P_{c,i,v,t} \le CI'_i.V_i, \quad \text{for all } i \in I, t \in T, \tag{17}$$

$$\sum_{n\in N} \vartheta_{i,n} = V_i, \quad \text{for all } i \in I, \tag{18}$$

$$\zeta_n\left(\sum_{d\in D}\sum_{v\in V} S_{i,d,v,t} + \sum_{k'\in K'}\sum_{v\in V} Y_{i,k',v,t}\right) \le \varphi_i.\vartheta_{i,n}, \tag{19}$$

$$\sum_{v\in V} u_v \left(\sum_{i\in I}\sum_{d\in D} S_{i,d,v,t} + \sum_{k'\in K'}\sum_{i\in I} Y_{i,k',v,t} + \sum_{d\in D}\sum_{j\in J} X_{d,j,v,t} + \sum_{k'\in K'}\sum_{j\in J} Z_{j,k',v,t} + \sum_{k'\in K'}\sum_{c\in C} O_{k',c,v,t} + \sum_{c\in C}\sum_{i\in I} P_{c,i,v,t} + \sum_{k''\in K''}\sum_{i\in I} N_{i,k'',v,t} \right) \le \aleph, \tag{20}$$

$$d_{k',t}, d'_{k',t}, PD_t, PI_t, \delta_{k',t}, \delta'_{k',t}, \delta''_{k'',t}, Y_{i,k',v,t}, Z_{j,k',v,t}, N_{i,k'',v,t}, X_{d,j,v,t}, Q_{d,t}, S_{i,d,v,t}, O_{k',c,v,t}, P_{c,i,v,t} \ge 0, \tag{21}$$

$$V_i, W_j, T_c, \vartheta_{i,n} \in \{0,1\}. \tag{22}$$

Eq. (1) maximizes the profit from the sale of products in the first-hand market through direct and indirect channels and the sale of products in the second-hand market. In this regard, the sales (income) amount is reduced due to construction, maintenance, shortage, and transportation costs. *Eq. (2)* maximizes product transfer reliability at different levels of the supply chain network. *Eqs. (3)* and *(4)* calculate customers' demand for new products in each time period based on uncertain demand and pricing strategy based on the leather whip effect. In *Relationships (5)* and *(6)*, the amount of transferred goods and lack of supply of demand in each time period of new products for each customer (direct and indirect channel) are calculated. *Eq. (7)* shows the amount of goods transferred to the second-hand market. *Eq. (8)* shows the new product transfer flow balance in distribution centers. Therefore, the amount of incoming and outgoing current in each distribution center is equal to that of the other. *Eq. (9)* shows the inventory amount of the new product at the end of each time period. *Eq. (10)* shows the amount of product returned from customers that can be recycled or destroyed. *Relationship (11)* shows the percentage of products that can be recycled and sold in the second-hand market. *Eq. (12)* calculates the amount of products that should be sold in the second-hand market. *Eqs. (13)-(17)* respectively show the limitations related to the capacity of production units, distribution centers, collection centers, storage warehouses for new products, and the capacity of the production unit of second-hand products. *Eq. (18)* guarantees that each production unit can use only one level of technology if it is built. *Eq. (19)* shows the maximum amount of greenhouse gas emissions due to producing new products in production units. *Eq. (20)* states that the total amount of gas released as a result of product transfer between levels of the supply chain network should not exceed a certain limit. *Relationships (21)* and *(22)* show the type of decision variables.

The closed-loop supply chain network model designed in this section consists of two decisions: facility location and transportation optimization. In the literature, many researchers have tried to prove that the above problems are Np-hard [23]. Therefore, it can be concluded that the model presented in this article is also one of the Np-Hard problems. Its degree of difficulty will be at least equal to the degree of difficulty of each location and transportation optimization problem. This means that by increasing the size of the problem, it will be impossible to solve the problem with exact methods. Therefore, meta-heuristic algorithms are used to solve the problem. This article has solved the proposed model in the steel industry by using the MOGWO algorithm.

4 | Analysis of the Results

Before analyzing the model, it is necessary to collect data on the problem first. Therefore, by using the literature on the subject, including searching sources, basic articles, and similar models, and collecting the main data from the steel industry of Iran, the ranges of the parameters of the problem have been determined. Experts' opinions in this industry have also been used to validate the data. The data of the problem after aggregation is obtained in the form of *Table 1*. Due to the uncertainty in the problem, the parameters of demand, transportation cost, and maintenance costs were in the form of triangular fuzzy numbers and based on the expectations of steel industry experts.

Table 1. Interval limits of problem parameters.

Parameter	Interval Limits		
$\lambda_{k'}, \rho$	0.3	φ_i	2500
$\lambda'_{k'}, \sigma$	0.2	ζ_n, u_v	$\sim U(1,2)$
γ_1	0.5	$\aleph$	4500
γ_2	0.4	Fv_i, Fw_j, Ft_c	$\sim U(1000,2000)$
CI_i	$\sim U(1000,1200)$	PR_t	$\sim U(30,40)$
CI'_i	$\sim U(500,700)$	CC_c	$\sim U(400,600)$
CD_d	$\sim U(400,600)$	$\pi_{k',t}, \pi'_{k'',t}$	$\sim U(20,80)$
CJ_j	$\sim U(500,800)$	$\lambda v_i, \lambda w_j, \lambda t_c$	$\sim U(0.4,0.6)$
$\widetilde{de}_{k',t}$	$\sim U(100,150) - \sim U(150,200) - \sim U(200,250)$		
$\widetilde{de}_{k'',t}$	$\sim U(50,70) - \sim U(70,100) - \sim U(100,120)$		
$\widetilde{Tr}_v$	$\sim U(1,1.5) - \sim U(1.5,2) - \sim U(2,2.5)$		
$\widetilde{H}_t$	$\sim U(0.5,0.75) - \sim U(0.75,1) - \sim U(1,1.25)$		

Before analyzing the model in larger sizes (larger dimensions of the steel industry) with the MOGWO algorithm, the mathematical model was validated using the epsilon constraint method. The reason for using the epsilon constraint method is the presence of two opposing objective functions in the problem. Therefore, the set of efficient solutions has been obtained by optimizing the first objective function and creating restrictions in the second objective function, as described in *Table 2*. In the upcoming analysis, the uncertainty rate in the problem is considered equal to 0.5. A small numerical example for validating the model includes 4 production units, 3 warehouses, 4 distribution centers, 3 collection centers, 4 first-hand customers, 3 second-hand customers, 3 transportation options, 2 production technologies, and two time periods.

Table 2. The set of obtained efficient answers.

Effective Solution	Total Profit	Total Reliability
1	68219.290	1147.475
2	68211.408	1178.507
3	68198.014	1207.522
4	67925.958	1239.272
5	67591.340	1241.648
6	66950.832	1247.223

Using the epsilon constraint method in GAMS 24.8.2 software, Baron solver has achieved 6 different efficient solutions. The results of the analysis of the efficient solutions show the conflict between the objective functions and each other. Thus, with the increase in reliability (improvement of the second objective function), the profit of the entire supply chain network has decreased (worsening of the first objective function). This shows that the more routes of product transfer, both in the indirect and direct channels, the decrease in profit from the network. The outputs of the strategic decisions of the problem show that 3 production units No. 1, 2, and 3 with technology level 2, 2 distribution centers No. 1 and 2, and a collection center No. 2 are needed to create a network. *Table 3* shows the real demand of first-hand market customers and the selling price of the product in the direct and indirect channels.

Table 3. The real demand of brand new market customers and the optimal selling price.

Customer	Direct Channel		Indirect Channel	
	Period 1	Period 2	Period 1	Period 2
1	197.562	213.589	181.337	196.959
2	194.699	199.555	178.474	182.926
3	204.828	207.850	188.603	191.220
4	199.129	206.321	182.904	189.962
Product price	104.303	106.905	127.481	130.661

The results of *Table 3* show that the real demand is a different amount than the potential demand due to price elasticity in the market. Based on this, it can be seen that the price of products in the first-hand market in the indirect channel is higher than in the direct channel due to the presence of intermediaries. The calculation

results show that due to the high cost of transportation in the indirect channel and the decrease in the profits of the supply chain network, 181,337 units in the 1st period and 196,959 units in the 2nd period have been created for the 1st customer. *Fig. 2* shows the amount of goods transferred between different centers of the supply chain network for periods 1 and 2.

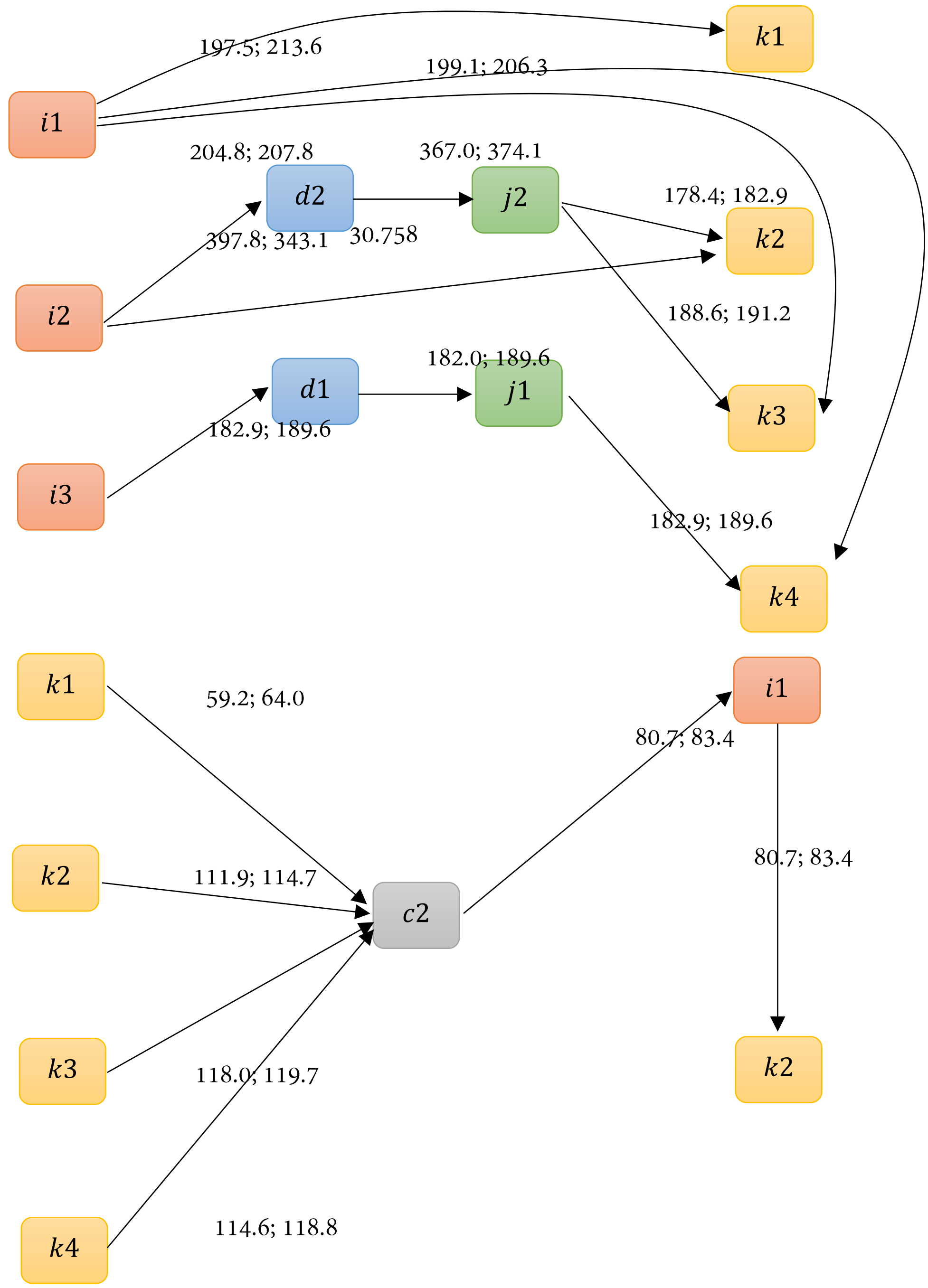

Fig. 2. Amount of goods transferred in the closed-loop supply chain.

Fig. 2 shows the amount of goods flow transferred between the different closed-loop supply chain network levels. A sensitivity analysis was conducted to investigate the changes in the objective functions relative to the model's parameters. *Table 4* shows the trend of changes in the values of the objective functions of the problem concerning the changes in the percentage of salable products in the second-hand market.

Table 4. Values of the objective functions of the problem in relation to changes in the percentage of salable products in the second-hand market.

σ	Total Profit	Total Reliability
0.1	68093.388	1262.982
0.2	68219.290	1258.655
0.3	68336.093	1250.723
0.4	68479.718	1247.223
0.5	68545.828	1230.438

Table 4 shows that with the increase in the value of σ, the total profit has increased due to the increase in the amount of sales in the second-hand market. Also, the total reliability has decreased due to the increased amount of transferred products. On the other hand, the most important parameter influencing the issue of product price elasticity in the direct and indirect channels is the one that directly affects the demand. Based on this, with the change in the product price elasticity values in the first and second-hand markets, the changes in the values of the objective functions of the problem have been investigated in *Table 5*.

Table 5. Values of the objective functions of the problem in relation to changes in product price elasticity.

γ_1	Total Profit	Total Reliability	γ_2	Total Profit	Total Reliability
0.3	421511.924	1488.732	0.2	693022.338	1488.732
0.4	169876.051	1488.732	0.3	202833.290	1371.647
0.5	68219.290	1247.223	0.4	68219.290	1247.223
0.6	14444.401	1145.241	0.5	4939.956	1176.322

The results show that with the increase in price elasticity of products in the first-hand and second-hand market, the amount of real demand in the network decreases. Hence, the profit of the supply chain network also decreases. So, with the excessive increase in price elasticity, the network faces losses. *Fig. 3* also shows the trend of changes in the values of the objective functions of the problem in relation to the changes of σ, γ_1 and γ_2.

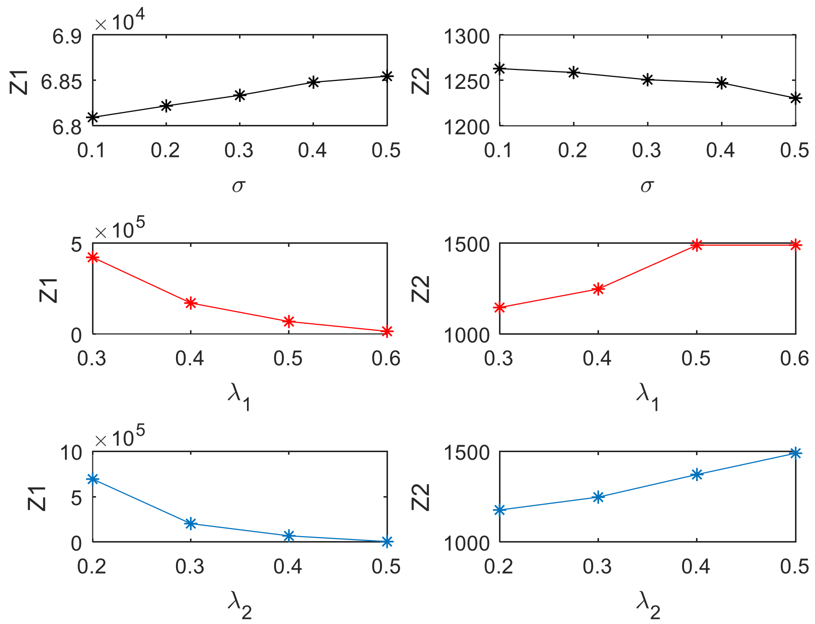

Fig. 3. Also, the trend of changes in the values of the objective functions of the problem in relation to the changes of σ, γ_1 and γ_2.

Finally, due to the uncertainty rate in the supply chain network and its impact on potential demand, another sensitivity analysis has been performed, and the changes in the objective functions in different uncertainty rates and product prices in different channels are shown in *Fig. 4*.

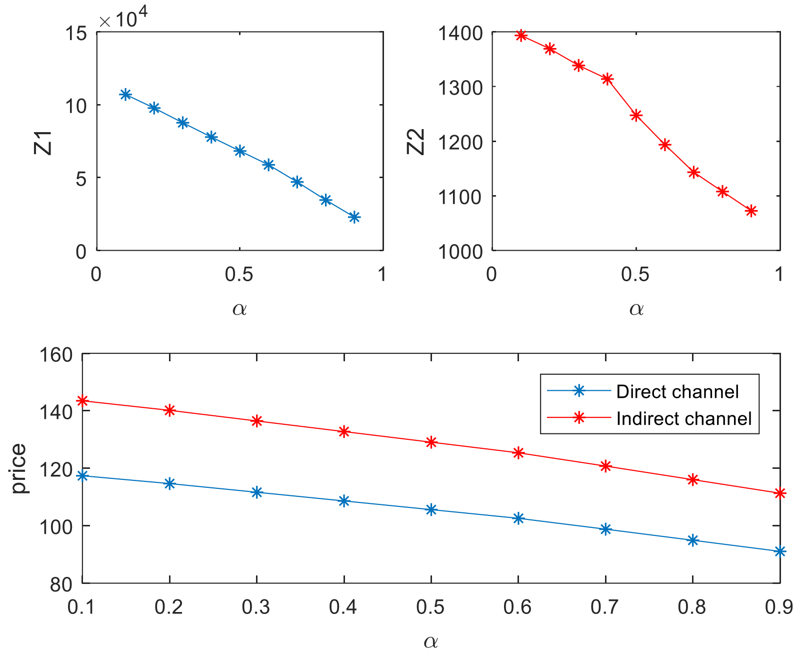

Fig. 4. The changing trend of the objective functions and the average prices in relation to the uncertainty rate.

Fig. 4 shows that with the increase in the uncertainty rate in the network, the amount of customer demand for the products has increased, and the increase in demand leads to a decrease in the price in the direct and indirect channels. As a result, with the price reduction, the profit of the entire supply chain network has decreased.

As mentioned, due to the Np-hardness of the mathematical model, the MOGWO algorithm has been used to solve the model in larger sizes in the steel industry. This algorithm can search the model faster with fewer calculation errors. Therefore, to increase its efficiency, reduce calculation errors, and increase the speed of the solution, the algorithm's parameter has been adjusted with the Taguchi method. This algorithm has 4 primary parameters, namely the maximum number of repetitions (Max-it), initial population (Nwolf), and coefficient of variation (A and C). Correct setting these parameters and determining their optimal value with Taguchi tests can significantly impact problem-solving. For this purpose, three different numbers have been suggested for each parameter, and the results of Taguchi's tests are expressed under the average graph of the S/N ratio. Max-it levels equal to 100, 200, and 300; N wolf levels equal to 50, 100, and 200; The levels of coefficient A equal to 1, 2, and 3; and finally, the levels of coefficient C equal to 2, 4, and 6 are suggested. The results of Taguchi's tests are specified in *Table 6*. In this Table, the value of RPD, which is unscaled, is determined by the test results.

Table 6. Results of Taguchi's tests in the MOGWO parameter setting.

Test	Max-it	Nwolf	A	C	Value	RPD
1	1	1	1	1	2455.114	0.1782
2	1	2	2	2	2241.318	0.0756
3	1	3	3	3	2674.333	0.2834
4	2	1	2	3	2243.818	0.0768
5	2	2	3	1	2271.346	0.0900
6	3	3	1	1	2242.642	0.0762
7	3	1	3	2	2626.083	0.2602
8	3	2	1	3	2106.569	0.0109
9	3	3	2	1	2083.819	0.0000

After carrying out 9 Taguchi tests and determining the value of RPD, the average graph of the S/N ratio has been obtained. In this chart, the goal is to select the highest available level for each parameter (*Fig. 5*).

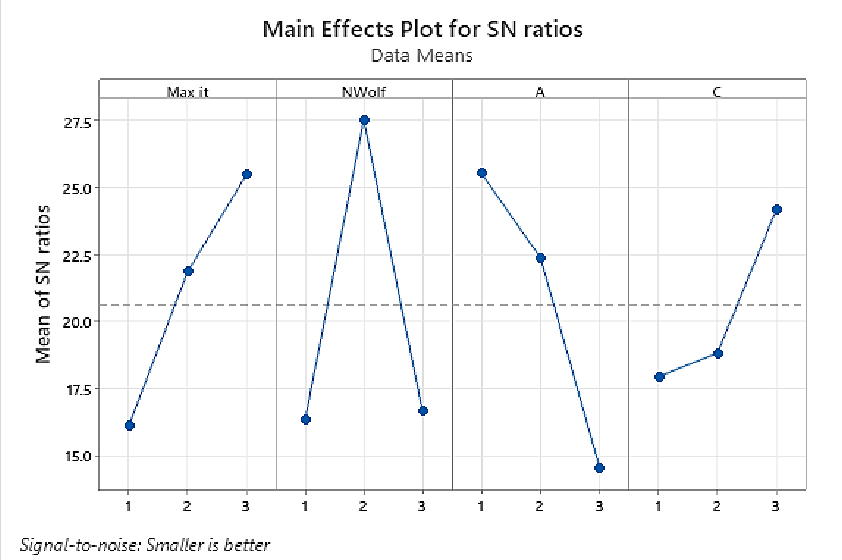

Fig. 5. Average graph of the S/N ratio of the MOGWO algorithm.

Fig. 5 shows that the Max-it parameter should be set to 300, the Nwolf parameter should be set to 100, The coefficient should be set to 1, and the C coefficient should be set to 6. After adjusting the parameter to increase the efficiency of the meta-heuristic algorithm, 15 numerical examples with the sizes presented for the steel industry in *Table 7* are considered. *Example 1* equals the numerical example presented in the previous section, which was used to validate the model.

Table 7. The size of different numerical examples.

Example	I	D	J	C	K	V	T	N
1	4	3	4	3	7	3	2	2
2	6	4	4	3	10	3	2	2
3	8	4	6	3	12	3	2	2
4	10	5	6	4	15	5	2	2
5	12	5	8	4	18	5	4	2
6	15	6	8	4	21	5	4	3
7	18	6	10	5	25	6	4	3
8	21	8	10	5	28	6	4	3
9	25	8	12	5	32	6	6	3
10	28	10	12	6	35	8	6	3
11	30	10	15	6	40	8	6	4
12	32	10	15	6	43	8	8	4
13	35	12	18	8	46	10	8	4
14	38	12	18	8	50	10	8	4
15	40	15	20	10	55	10	8	4

The number of effective solutions for the numerical example number 1 of the steel industry in *Table 7* with the epsilon limit method is equal to 6, and with the MOGWO algorithm is equal to 10. *Fig. 6* compares the Pareto front resulting from the solution of this numerical example.

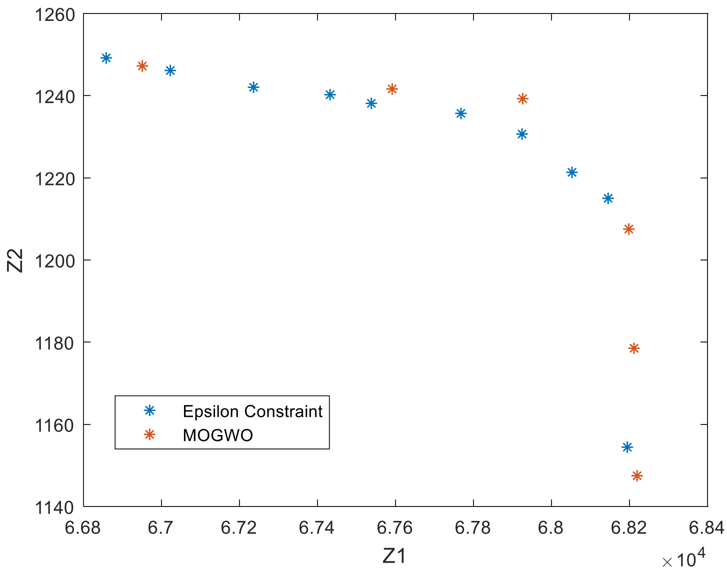

Fig. 6. Pareto front obtained from solving the numerical example in the steel industry.

Due to the multiplicity of effective solutions between the two solution methods, various indicators have been used to compare the efficiency of the two solution methods. Based on this, it can be seen that:

I. The number of efficient solutions in the epsilon constraint method is equal to 6, and in the MOGWO algorithm is equal to 10. Obviously, the MOGWO algorithm has a higher efficiency in this index than the epsilon method.

II. The maximum expansion value in the epsilon limit method equals 9735.26; in the MOGWO algorithm, it equals 8244.68. Due to the higher value of this index in the epsilon limit method, the efficiency of this method is also proven

III. The value of the metric distance in the epsilon limit method is equal to 0.627; in the MOGWO algorithm, this value is equal to 0.522. This shows that the distance of the obtained efficient solutions has the same extent. As a result, the MOGWO algorithm has been effective in achieving this index.

IV. The efficient solutions of numerical example 1 were also obtained by the epsilon constraint method in a period of 68.11 seconds and by the MOGWO algorithm in a period of 18.67 seconds. This shows the high efficiency of this algorithm.

The above results show that except for the index of the largest extent, the algorithm used has a high efficiency in other indices, and it is possible to solve other numerical examples with more confidence. All the indicators obtained from solving different numerical examples with the MOGWO algorithm are shown in *Table 8*.

Table 8. MOGWO algorithm performance indicators.

Example	The Number of Effective Answers	The Greatest Extent	Metric Distance	Solution Time
1	10	8244.68	0.522	18.67
2	29	12774.98	0.269	23.14
3	28	13888.71	0.522	28.61
4	17	12804.52	0.403	35.60
5	32	9754.31	0.443	45.14
6	15	14865.27	0.566	56.94
7	23	11778.09	0.332	73.54
8	29	13934.50	0.613	96.73
9	22	11816.04	0.528	128.67
10	15	12234.67	0.613	166.34
11	29	14285.85	0.388	218.54
12	15	13868.05	0.493	279.13
13	29	8502.31	0.457	٣٤٩,٦٨
14	21	9720.93	0.346	٤٢٨,٦٤
15	17	13996.59	0.342	٥٢٢,٣٩

Based on the results of *Table 8*, an important issue can be reached: the fact that the investigated problem is NP-hard. Yera, with the increase in the size of the numerical examples, the problem-solving time is increasing exponentially. Based on this, *Fig. 7* shows the average indices obtained from solving different numerical examples with the MOGWO algorithm.

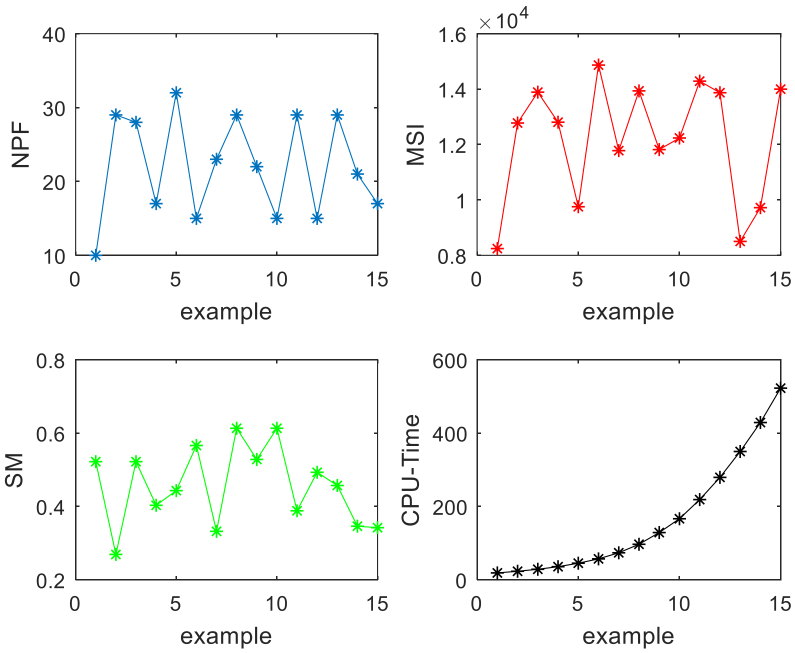

Fig. 7. Average numerical indicators in different examples.

5 | Conclusion

This article presented a comprehensive model of the reverse supply chain network, and the important issue of pricing based on market elasticity relative to alternative products in fuzzy conditions was discussed. This network comprised production units, warehouses, distribution centers, first-hand and second-hand customers, and collection centers. The goal was to determine the optimal number and location of production units, distribution, and collection centers at a strategic level. Also, at the tactical level, the goal was to determine the real demand of customers from two direct and indirect channels. Production units can send their goods directly to customers. Determining the actual demand was based on market elasticity for substitute products, market elasticity in other channels, and product prices. Based on this, the optimal amount of

production and product storage for each period were determined. To make the most appropriate strategic and tactical decisions, two objective functions of maximizing the profit of the entire supply chain and maximizing reliability were defined. The objective function was to maximize the profit of the entire supply chain based on the most important principle, which is to determine the product price in the direct and indirect channels in each time period. Due to the uncertainty in the potential demand, maintenance, and transportation costs, the fuzzy programming method was used. Using the uncertainty rate, this method determined the real demand in the first-hand and second-hand market. Calculation results in the steel industry showed that the product price in the direct channel is lower than the product price in the indirect channel due to the absence of intermediaries. Also, the increase in the uncertainty rate in the network, which leads to an increase in the potential and real demand in the market, will lead to a decrease in the selling price. The analysis of the two-objective model also shows that with the increase in reliability, the profit of the entire supply chain network decreases.

Two precise and ultra-innovative methods were used to solve the problem in the steel industry. In these methods, which were compared for numerical example 1, 6 efficient solutions were obtained from the epsilon limit method, and 10 efficient solutions were obtained from the MOGWO algorithm. Also, the examination of the comparison indexes showed that the MOGWO algorithm has a higher efficiency than the epsilon method in achieving the index of the highest number of efficient solutions, the lowest metric distance, and the lowest solution time. On the other hand, the epsilon method has only the highest expansion compared to the MOGWO algorithm. The analysis of 15 different numerical examples also showed that as the problem size increases, the time to solve the problem increases exponentially, which indicates that the problem is NP-hard. In future research, it is suggested that several products in the mathematical model be considered. Also, two steps are suggested for making different pricing decisions.

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